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# Using an Advanced Vehicle Simulator (ADVISOR) to Guide Hybrid Vehicle Propulsion System Development

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# Outline

- Introduction to ADVISOR
- Description of 5 vehicles modeled
- Sensitivity parameters for the vehicles
- Mapping out HEV design space
- Preliminary look at effect of hybridization
- Tradeoffs to achieve 80 mpg (3X) using sensitivity parameters and HEV design space
- Conclusions

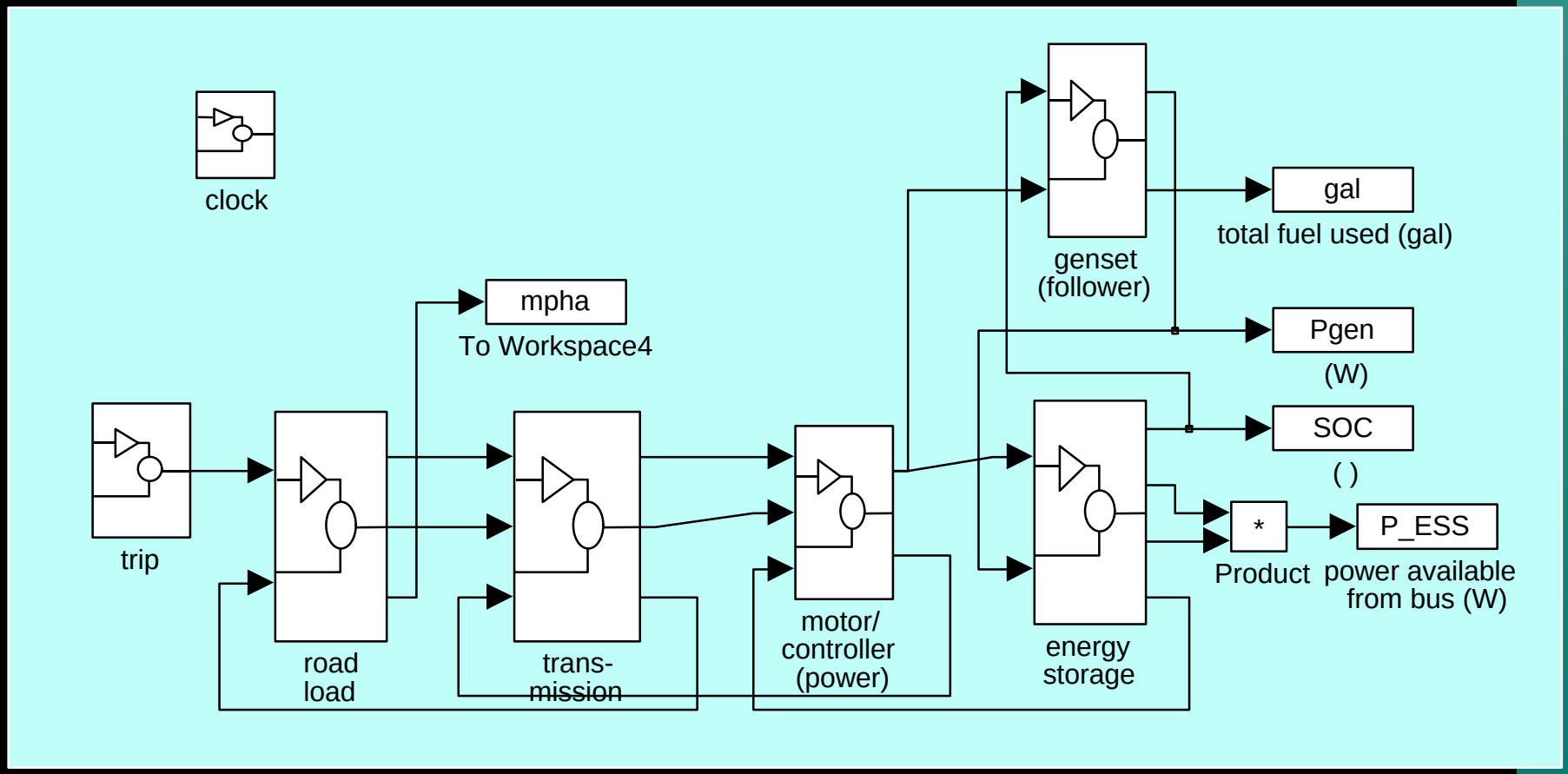
# Introduction to ADVISOR

- Model first created at NREL in November 1994
- Created to explore propulsion system combinations for:
  - U.S. Department of Energy
  - Big 3 hybrid subcontract support
- Programmed in Simulink/MATLAB environment
  - graphical, object-oriented language
- Flexible environment makes it ideal for modifying & improving control strategies

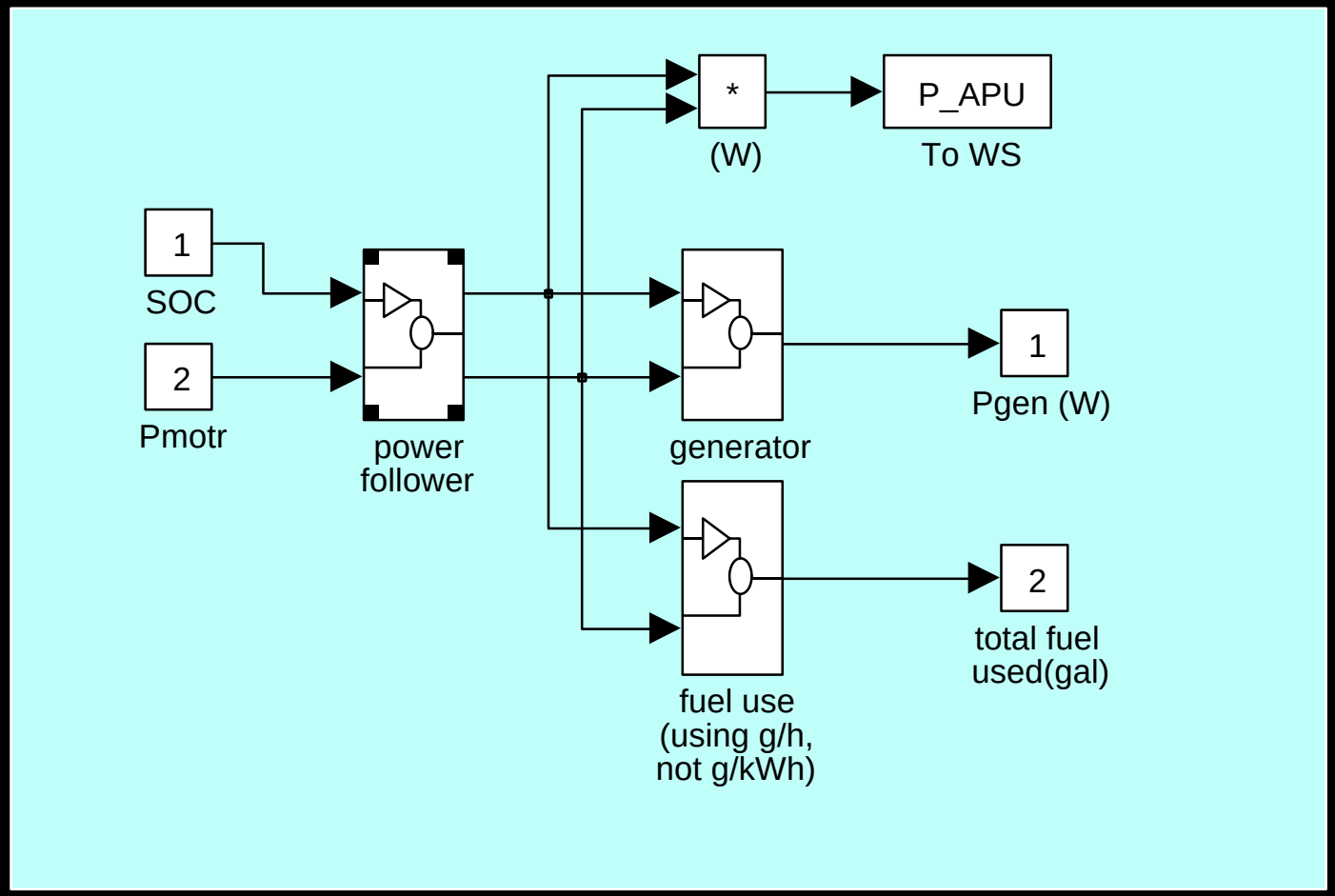
# Introduction to ADVISOR (cont.)

- Quasi-static modeling approach for comp. data
  - series of discrete steps in time at which components are assumed to be at steady-state
- Capable of modeling HEVs, EVs, conventional vehicles
- Validations and correlations to verify accuracy:
  - sources of component data are validated models from universities, OEMs, and other national labs
  - Accuracy of calculations checked through correlation of system model with industry

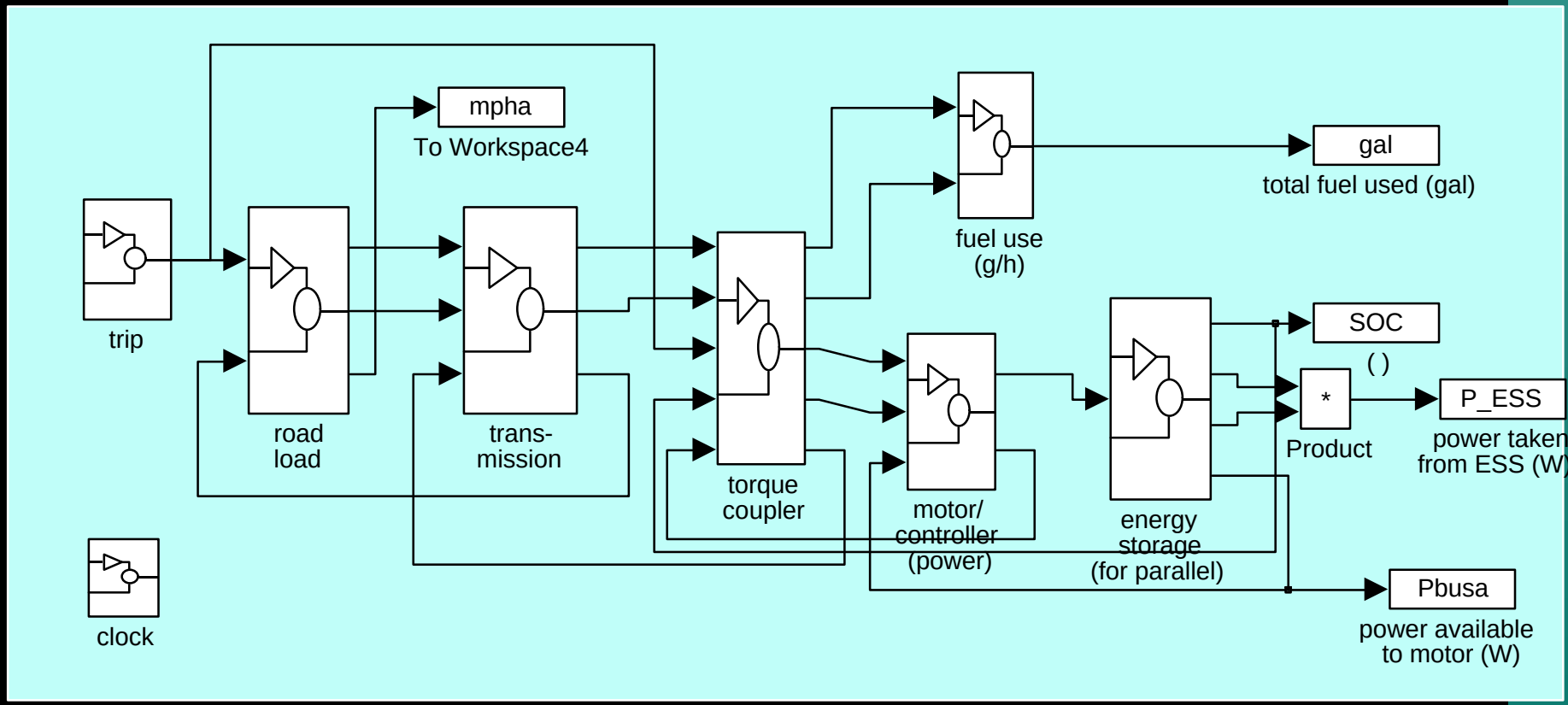
# Series hybrid model: top level



# Series model: genset & control strategy, example of layered structure



# Parallel hybrid model: top level



# Vehicles modeled

- Conventional vehicle (baseline of 26.6 mpg)
  - but with adv. diesel and manual transmission (38.7 mpg)
- Conventional vehicle that's been hybridized
  - 1.70X parallel hybrid vehicle (45.3 mpg)
- Two 3X (>80 mpg) vehicles
  - Parallel 3X vehicle (81.8 mpg)
  - Series 3X vehicle (80.5 mpg)
- Lightweight conventional vehicle
  - parallel 3x vehicle without hybridization (65.4 mpg)

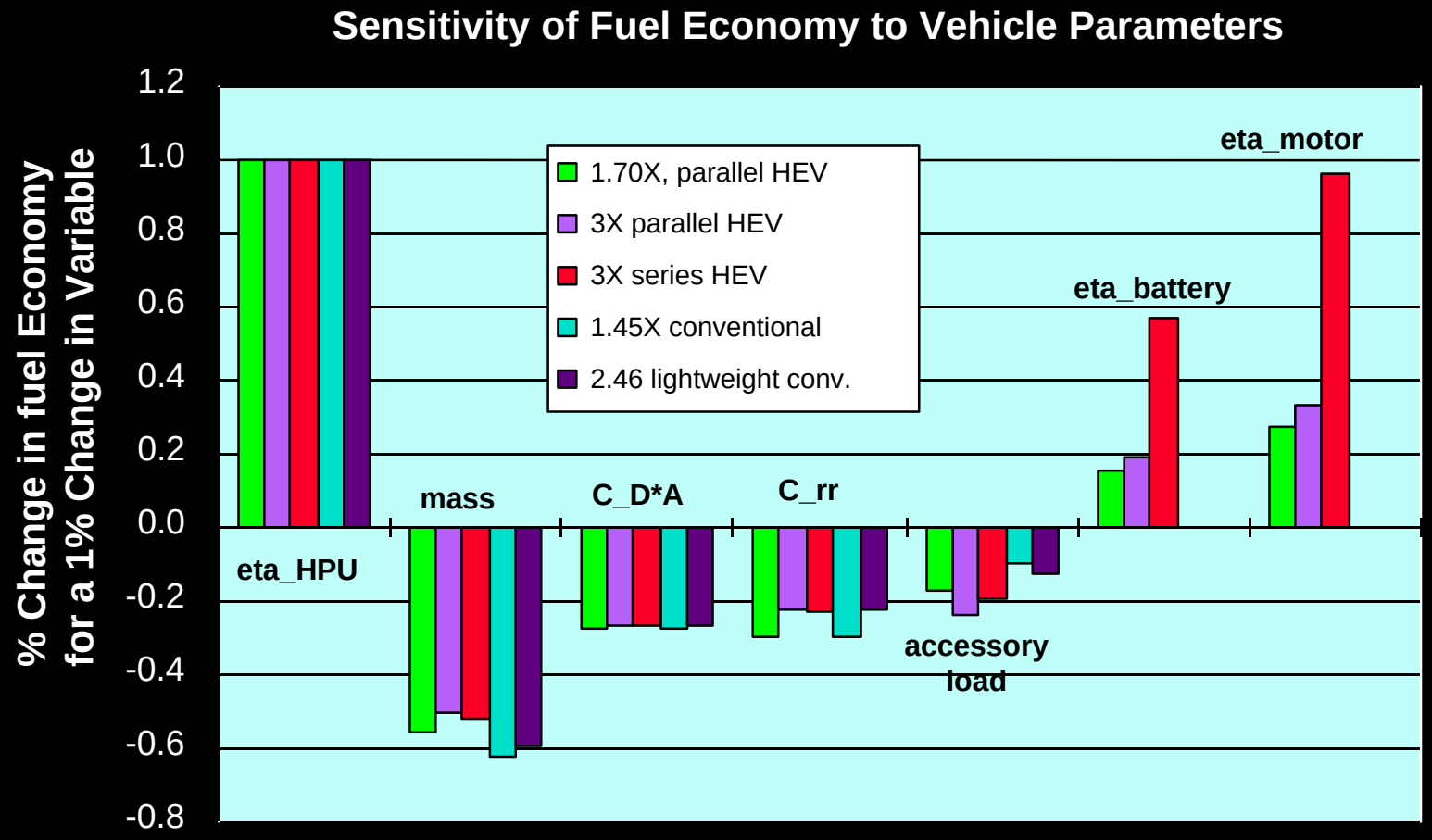
# Assumptions

- Mass
  - Lightweight conventional and two 3X vehicles: 1000 kg
  - 1.45X conventional diesel and 1.70X parallel: 1611 kg
- Other improvements for lightweight vehicles
  - Improved aero. ($C_DA$ of 0.4$m^2$ for 3X vehicles vs. 0.7$m^2$)
  - Improved rolling resistance (0.008 vs. 0.011)
- Performance equivalence among all vehicles
  - 0-60 in 12 seconds, gradeability at 55 mph indefinitely
- Linear scaleability of HPU and motor/controller
- Detailed tables with sources are in Proceedings

# Sensitivity parameters for the vehicles

- Methodology
  - +5%, -5% change in input parameter, holding others constant, resulting in two fuel economies for these points
  - Using these two points, the change in fuel economy was calculated for this 10% change in input parameter
- Can be used to obtain quick answers
  - They allow you to come up with rules of thumb
- Provide insight into where attention should be focused...quantification of benefits for improving a particular technology or vehicle parameter
- Shouldn't be trusted beyond about +/- 10%

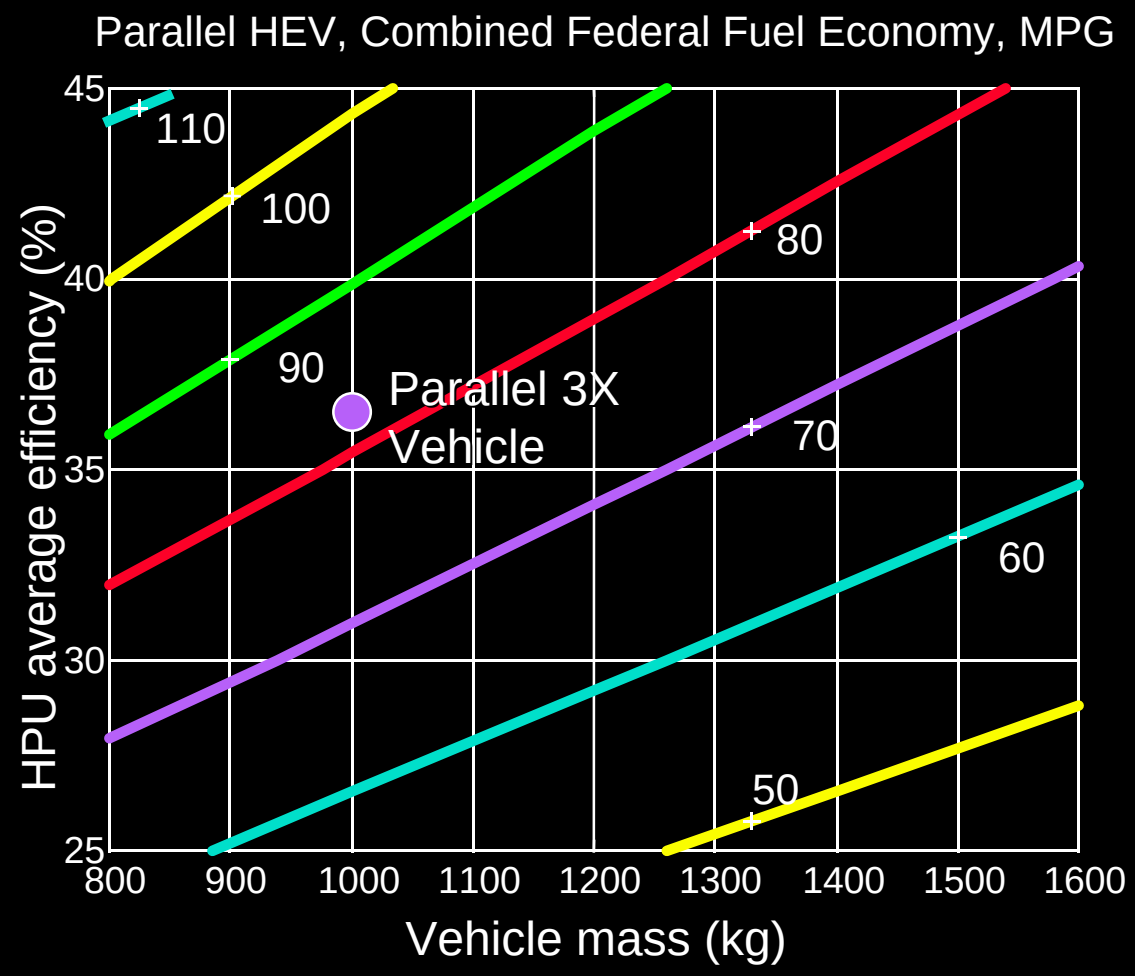
# Sensitivity parameters



# Mapping out the HEV design space

- In a parametric study, we vary some variables, holding all others constant
- Parametric runs of 2 or more variables can be useful in mapping out  a region of design space
- When changing mass, performance equivalence (accel. and gradeability) is always maintained by scaling components
- Can easily see that we can't get to 3X (with a 25% efficient HPU) by simply reducing mass
- 3X parallel vehicle plotted for reference

# Fuel Economy as a Function of HPU Efficiency and Vehicle Mass for Parallel HEV



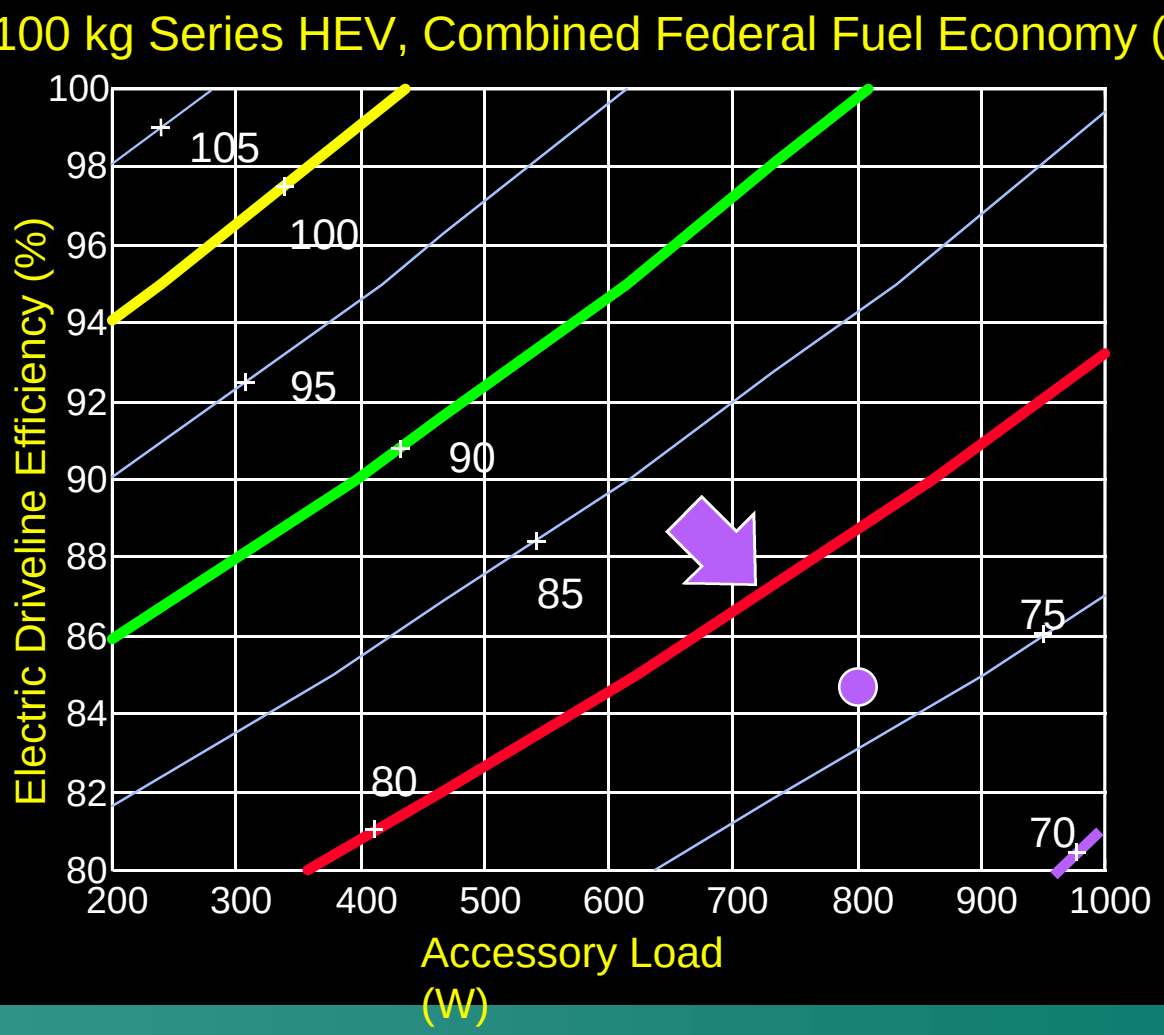
# Preliminary look at effect of hybridization

- Comparing the two conventional drivetrain vehicles (lightweight and heavy) with the three hybrids of the same mass
- 1.45X conventional vs. 1.75X parallel hybrid
  - 17% improvement due to just hybridization (same mass)
- 2.46X lightweight conventional vs. 3X vehicles
  - 24% improvement (avg. of improvement for series, parallel)
- Appears as though the effect of hybridizing is stronger with efficient lightweight vehicles

# Using HEV design space to examine effect of adding 100 kg to series HEV

- Both of the 3X series and parallel hybrids were assumed to have a mass of 1000 kg
- Can use sensitivity parameters to look at effect of adding 100 kg to series vehicle
  - Example: if somebody claims series hybrids will always be heavier by this amount due to a larger motor and a heavier battery pack
  - (10% increase in mass) X (-0.518 sensitivity to mass) = 5.18% decrease in fuel economy (~4 mpg) leads to a 76 mpg vehicle
  - Move from 80 mpg contour to dot at 76 mpg with accessory load of 800W and 84.5% avg. driveline efficiency

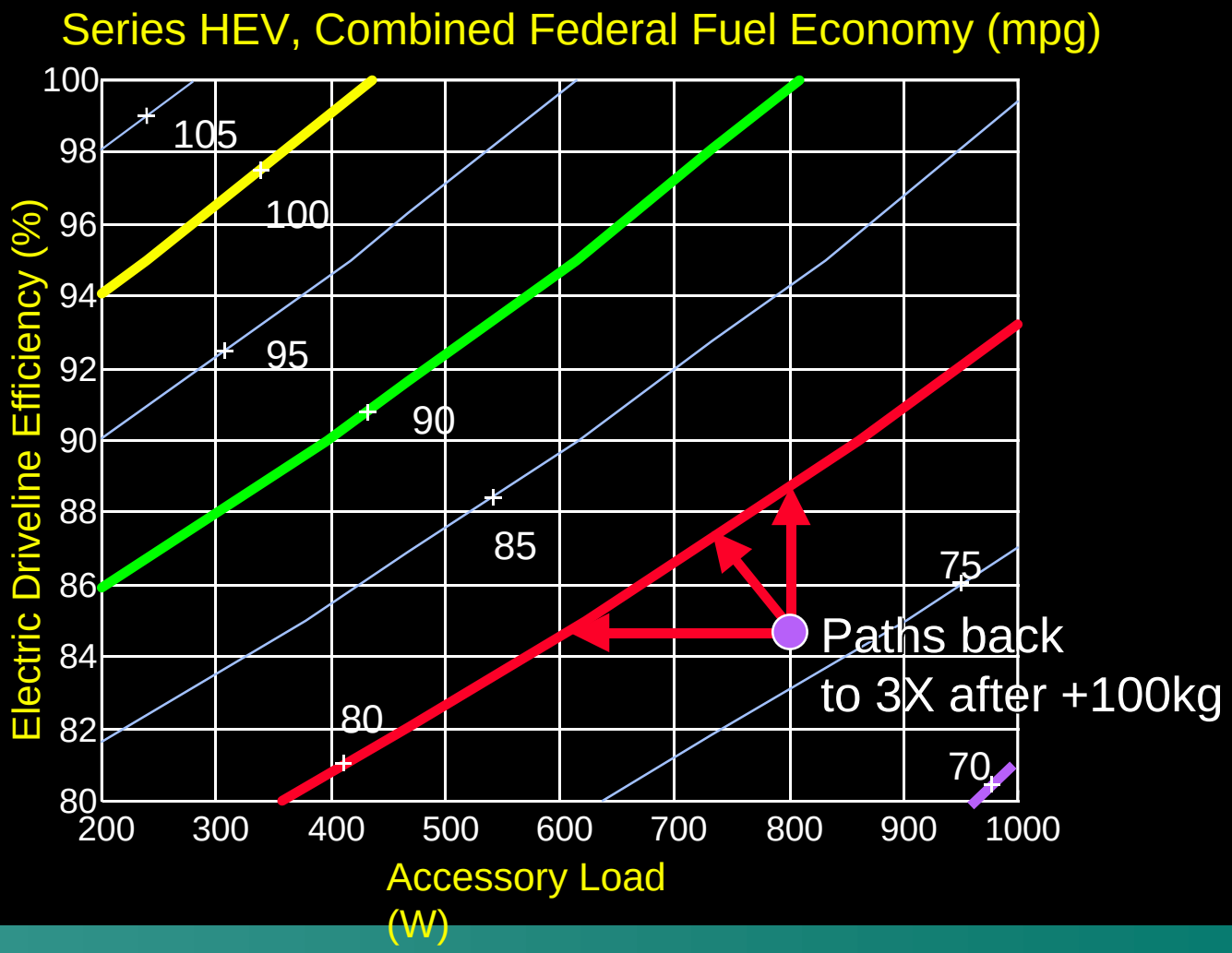
# Fuel economy design space: driveline efficiency and accessory load



# Using HEV design space (cont.)

- Then use HEV design space to look at other “paths” to return to red 80 mpg fuel economy contour
- Example: take driveline efficiency and accessory load design space
  - can either reduce accessory load by 200W,
  - can increase driveline avg. efficiency from 84.5% to 89%,
  - or some combination of the two

# Using HEV design space (cont.)



# Conclusions

- Modeling shows that hybridization is useful in improving fuel economy, but that a systems-level approach is needed to reach the 3X fuel economy goal
- Having sensitivity coefficients for vehicle input parameters is useful for being able to quickly determine effect of improving one aspect of vehicle
- Being able to map out HEV design space in a region of interest provides insight into systems-level tradeoffs
- Using a hybrid simulator in the Simulink/MATLAB environment (such as ADVISOR) provides flexibility to include new control strategies and new component models